The international GPS Service for Geodynamics - Benefits to Users

James F. Zumberge, Ruth. E. Neilan (Jet Propulsion Laboratory, California institute of Technology),
Gerhard Beutler, Werner Gurtner (Astronomical institute, University of Berne)

BIOGRAPHIES

James 1. Zumberge serves the International GPS Service for Geodynamics (IGS) both as a member of its Central Bureau, as well as a member of one of seven IGS Analysis Centers, He received his Ph.D. in physics from the (California Institute of Technology in 1981, and worked on industrial applications of nuclear physics at MDH industries in Monrovia, CA, before joining the Space Geodesy and Geodynamics Systems Group at Caltech's Jet Propulsion Laboratory (JPL) in 1990.

Ruth E. Neilan is the Director of the IGS Central Bureau, funded by NASA at JPL in Pasadena, CA. She received her M.S. in Civil and Environmental Engineering from the University of Wisconsin--Madison in 1986 and has been involved in the coordination and establishment of the GPS Global Network since 1987. During the period 1987 until 1993 she was the Project Manager for regional GPS investigations funded by NASA's Geodynamics Program.

Gerhard Beutler currently is the chairman of the IGS. He received his Ph.]). in astronomy from the University of Berne, Switzerland. Subsequently he worked on several projects in fundamental astronomy. The development of algorithms to process observations of the GPS eventually led to the development of the Bernese GPS Software Package and to the operation of the CODE processing center of the IGS.

Werner Gurtner was a member of the IGS Oversight Committee, helped organize the data flow within the IGS network, and developed the IGS Central Bureau Information System. He received his Ph.D. in technical sciences from the Federal Institute of Technology in Zurich, Switzerland in 1978. He is a researcher at the Astronomical institute of the University of Berne, Switzerland, station manager of the institute's observatory and one of the authors of the Bernese GPS Soft ware.

ABSTRACT

The International GPS Service for Geodynamics is an international scientific service which began formal operation at the beginning of 1994, following several years of planning [1] and a 1*/2-year pilot service, The IGS collects, archives, and distributes GPS observation data sets, and uses these to generate high accuracy GPS satellite ephemerides, earth rotation parameters, coordinates and velocities of the IGS tracking stations, GPS satellite and tracking station clock information, and ionospheric information.

To accomplish its mission, the IGS consists of a network of GPS tracking stations, Data Centers, Analysis Centers, an Analysis Coordinator, a Central Bureau, and a Governing Board, The accuracies of IGS products are sufficient to 'support current scientific objectives, including the realization of the international Terrestrial Reference Frame (ITRF), monitoring of the earth's rotation and deformation of its liquid and solid components, ionospheric monitoring, and scientific satellite orbit determination. A Central Bureau information System (CBIS) allows public access to IGS products, which include precise GPS ephemerides within 2-3 weeks of real time. IGS contributors and customers communicate through electronic mail, and exchanges are archived for future reference.

INTRODUCTION

The primary objective of the International GPS Service for Geodynamics is to provide a service to support, through GPS data products, geodetic and geophysical research activities. Cognizant of the immense growth in GPS applications the secondary objective of the IGS is to

support a broad spectrum of operational activities performed by governmental or 'selected commercial organizations. The service also develops the necessary standal-ds/specifications and encourages international adherence to it's conventions.

A proof of concept for the International GPS Service for Geodynamics was conducted with a three-month campaign during June-September 1992 [2], and was continued through a pilot service until the formal establishment of the IGS in 1993 by the International Association of Geodesy (IAG). The routine. IGS started on January 1, 1994. IGS operates in close cooperat ion with the International Earth Rotation Service (11 ;RS). The IGS *Terms of Reference [3]* describes in broad terms the goals and organization of the. IGS.

The IGS collects, archives, and distributes GPS observation data sets of sufficient accuracy to satisfy the objectives of a wide range of applications and experimentation. These data sets are used by the IGS to generate data products, including high accuracy GPS satellite ephemerides, earth rotation parameters, coordinates and velocities of the IGS tracking stations, GPS satellite. and tracking station clock information, and ionospheric information.

in particular the accuracies of these products are sufficient for the improvement and extension of the international Terrestrial Reference Frame (ITRF), the monitoring of solid earth deformations, the monitoring of earth rotation and variations in the liquid earth (sea level, ice-sheets, etc.), for scientific satellite orbit determinations, and ionosphere monitoring.

To accomplish its mission, the IGS consists of a network of GPS tracking stations, several Data Centers, Analysis Centers, an Analysis Coordinator, a Central Bureau, and a Governing Board.

OI)ICRATION OF THE IGS

Shown in Figure 1 is the distribution of sites that comprise the IG S global network of GPS tracking receivers. Within the next few years, expansion of the global network will address the paucity of sites near longitude 90°E, with planned coverage in Central Asia and islands in the Indian Ocean.

1 iach site has a high-precision dual-frequency P-code receiver which records measurements at 30-sec intervals. IGS Operational Data Centers (Table 1) are in direct contact with the tracking sites, and are responsible for fetching raw receiver data, formatting it in a common
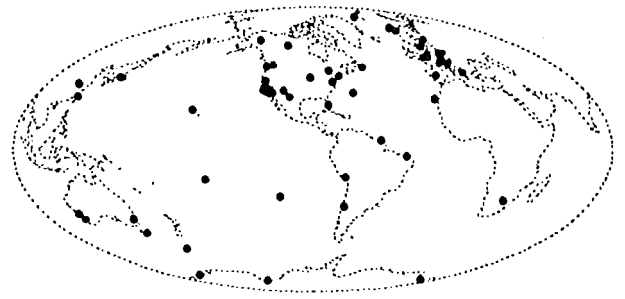
Figure 1 Network of IGS Tracking Stations, as of September 1, 1994

standard [4], and forwarding the. data to Regional or Global Data Centers.

Reformatted tracking data from several Operational Data Centers are collected at Regional Data Centers. A local archive of the data received is maintained, and the data arc transmitted to the Global Data Centers. Regional Data Centers thus serve to reduce traffic on electronic networks.

TABLE 1. IGS DATA CENTERS

Operational & Regional

National Oceanic and Atmospheric Administration	US
Institut fur Angewadte Geodäsie	Germany
Natural Resources, Canada	Canada
Norwegian Mapping Authority	Norway
Jet Propulsion Laboratory	US

Global

NASA/Goddard Space Flight Center	US
Institut Géographique National	France
Scripps institution of Oceanography	US

The Global Data Centers serve as interfaces to the Analysis Centers and the external user community. 'I'heir purpose is to receive/retrieve, archive, and provide on-line access to tracking data. In addition, Global Data Centers provide access to Analysis Center products.

l'here arc currently seven IGS Analysis Centers (AC's) (Table 2) - three in the US, one in Canada, three in Europe - that routinely analyze some subset of the data from the IGS global network, AC's compute precise GPS

ephemerides and earth orientation parameters. Daily results are. posted periodically, typically once each week.

The IGS Analysis Coordinator - Jan Kouba at Natural Resources, Canada --is responsible for producing a single IGS orbit, based on the combination of orbits from the separate AC's [5]. Because of consistency checks, the combined orbit is largely free of some systematic errors that occasionally remain in results from individual AC's. Agreement among AC's in GPS satellite ephemerides is generally at the level of 10 to 30 cm. It is estimated that the absolute accuracy of the IGS orbits is at least one order of magnitude better than the broadcast ephemeris, even when anti-spoofing is in effect.

TABLE 2. IGS ANALYSIS CENTERS

Astronomical Institute- University of Berne Switzerland	
European Space Agency	Germany
GeoForschungsZentrum	Germany
Jet Propulsion Laboratory	US
National Oceanic and Atmospheric Administration	US
Natural Resources, Canada	Canada
Scripps Institution of Oceanography	US

Estimates of earth orientation and station coordinates from the AC's are coordinated with the IERS [6]. Through the IGS, GPS-derived station locations are contributing more and more to the ITRF. **Over the next few years, a major goal of the IGS will be to include in the ITRF** the coordinates of a number of sites that comprise dense regional GPS networks,

Table 3 summarizes the approximate accuracies of IGS orbits, clocks, earth orientation, and station locations ([6], [7], [8]).

CENTRAL BUREAU INFORMATION SYSTEM

'I'he Central Bureau Information System (CBIS) provides public access to products of the IGS, and also provides a means of electronic messaging among IGS participants. The system, developed in late 1993 by Werner Gurtner, runs automatically.

The CBIS is a client on the Internet's World Wide Web, allowing access with user-friendly Mosaic and Lynx interfaces. For example, on most Unix systems, the command

TABLE 3. APPROXIMATE ACCURACIES OF IGS PRODUCTS

GPS ephemerides	10 - 30 cm
GPS clocks	0.5 – 5 nsec
earth orientation - pole	0:2-0.7 mas
earth orientation - length of day	0.1- 0.5 ms/day
station coordinates (annual solutions)	3 111111- 3 cm

lynx http: //igscb. jpl .nasa.gov/

will connect the user to the CBIS. For those with X-window terminals, xmosaic for Unix systems, or the equivalent Macintosh or Window's application, allows a graphical interface to the CBIS.

At the top level of the CBIS one views the following:

```
The Central Bureau, funded by NASA at
Cal tech's Jet Propulsion Laboratory,
supports an Information Service:
```

* **IGS Mail**: An archive of exchanges among IGS participants.

* **IGS** Reports: An archive of reports from IGS Data and Analysis Centers.

* **Regional Mail**: An archive of exchanges among those interested in specific regional GPS networks.

```
These collections, with other data, are
also available through anonymous FTP.
```

Categories in bold can be selected for further exploration. By sending a message to igscb@igscb. jpl.nasa.gov, you can request that your Internet c-mail address be added to one or more of the mail and report distribution lists. The **anonymous** FTP category is explained in more detail in "l'able. 4, where. top-level files and directories are given.

BENEFITS TO USERS

The. IGS has been in formal operation for less than a year, and detailed analysis strategies that exploit the qualities of its data and products are still being developed.

High quality Rinex tracking data from the global tracking network, GPS ephemerides that are more accurate than the broadcast orbits by at least an order-of

magnitude, and precisely -dctcrminc.d locations of dozens (and eventually hundreds or more) of sites distributed over the entire globe, all provide benefits to users.

TABLE 4. TOP-LEVEL OF CBIS ANONYMOUS FTP AREA

files:	IGSCB.DIR NEWS.TXT README.TXT TREE.TXT
cen ter	contains information on the various IGS Centers (Analysis, Data, etc.)
data	indicates where - at which Data Centers - Rinex data reside
general	miscellaneous information on GPS, 1 AG, and IGS, including the IGS Terms of Reference
ma i 1	contains indices of mail messages, and the messages themselves
product	contains Analysis Center products: precise ephemcrides, earth orientation, weekly summaries
software	contains source code for CWIS-exploring utilities
station	contains information on IGS stations

Geodynamics investigators who use GPS in local regions can include data from onc or more nearby IG S stations, fix the site coordinates from such stations to their ITRF values, and fix GPS satellite positions to their IGS-determined values. By doing so the investigator can reduce data from his own network with maximum accuracy and minimum computational burden. Furthermore, the results will be in a well-defined global reference frame.

1/or more information contact

ACKNOWLEDGMENTS

REFERENCES

[1]   Mueller, 1. I., G. Beutler, The international GPS Service for Geodyanmics -- Development and Current Structure, *Proceedings of the Sixth International Geodetic Symposium on Satellite Positioning*, Columbus Ohio, March 1992, pp. 82%835.

[2]   Beutler, Gerhard, 1993, The 1992 IGS Test Campaign, Epoch '92, and the IGS Pilot Service: An Overview, in *Proceedings of the 199.? IGS workshop*, G. Beutler, E. Brockmann, editors, March 25-26, 1993, Bern, Switzerland, pp. 3- 9.

[3]   Mueller, 1. I., International GPS Service for Geodynamics: Terms of Reference, in *Proceedings of the 1993 IGS Workshop*, G. Beutler, E. Brockmann, editors, March 25-2.6, 1993, Bern, Switzerland, pp. 10-14.

[4]   Gurtner, Werner, RINEX- The Receiver-independent Exchange Format, in *GPS World*, July 1994, V. 5,110.7.

[5]   Beutler, Gerhard, Jan Kouba, Tim Springer, 1993, Combining orbits of the IGS processing cent res, in *Proceedings of the IGS Analysis Centre Workshop*, Jan Kouba, editor, October 12-14, 1993 Ottawa, Canada, pp. 19-55.

[6]   Feissel, M., and N. Essaïfi, editors, *1993 IERS Annual Report*, July, 1994; Central Bureau of IERS, Observatoire de Paris; 61, avenue dc l'Observatoire; F-75014; Paris, France.

[7]   Jan Kouba, editor, *Proceedings of the IGS Analysis Centre Workshop*, October 12-14, 1993, Ottawa, Canada.

[8]   Blewitt, Geoffrey, Advances in Global Positioning System "1'ethnology for Geodynamics Investigations: 1978–1992, in *Contributions of Space Geodesy to Geodynamics: 7'ethnology*, David E. Smith, Donald L. Turcotte, Editors, Geodynamics Series volume. 25, American Geophysical Union, Washington, D.C.